# Observations and Modeling of the West Florida Continental Shelf Circulation

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## LONG-TERM GOALS

My long-term goal is improved understanding of how physical processes affect material property distributions on continental shelves. These include biological (red-tide algae and fish larvae), chemical (nutrients), and geological (sediment resuspension/transport) measures, and the physical responses of the currents and sea level.

## OBJECTIVES

To achieve this goal I must accomplish a related set of objectives. In logical order, these are. 1) I am describing of the West Florida Continental Shelf (WFS) circulation on tidal, synoptic, seasonal, and inter-annual time scales. 2) I am determining the relative influences of local and deep-ocean momentum and buoyancy fluxes in driving the WFS circulation. 3) I am describing how local and deep-ocean forcing functions affect along-shelf and across-shelf material transports, with emphasis on the inner-shelf. 4) I am determining how these physical factors are related to biological (primary productivity), chemical (nutrient distributions), and geological (sediment resuspension) processes. 5) I am developing diagnostic/prognostic information for WFS experimentation and for contributing toward an Autonomous Ocean Sampling Network for Navy purposes. 6) I am developing capabilities for real-time reporting of environmental fields to support AUV operations, test sensors, develop prognostic physical and biological models, improve regional weather forecast models, and provide information for emergency managers. 8) I am observing the responses of the near bottom log-layer region to assess sediment resuspension events and their effects upon water column IOPs.

## APPROACH

My approach combines *in situ* measurements and numerical circulation modeling. Along with colleagues, I marshaled resources from several projects. The measurements consist of a moored array complemented by monthly hydrographic cruises. The array uses bottom and surface mounted acoustic Doppler current profilers (ADCP) for currents. The bottom moorings include temperature/salinity (T/S), and pressure sensors, and a smaller subset of these include shorter term deployments of sediment resuspension packages (near bottom acoustic current meters and optical instruments). The surface moorings include surface meteorological instruments and a vertically distributed set of T/S. The array, at its peak, consisted of 13 moorings: 6 surface and 7 subsurface. In place from June 1998 through August 2001, it is now scaled back for monitoring and some process experimentation (seven moorings in total). The complementary hydrographic data (with G. Vargo and J. Walsh, USF) also

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14. ABSTRACT
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exist from June 1998 to the present, augmented with bi-weekly cruises off Sarasota to the 30m isobath (G. Kirkpatrick, Mote Marine Laboratory). Other data exist to the north in the Florida Big Bend (W. Sturges, FSU), and to the south in Florida Bay (T. Lee, RSMAS). I am interacting with P. Howd and other USF geologists on sediment studies. Remote sensing includes satellite AVHRR and ocean color imagery (F. Muller Karger, USF). Numerical circulation modeling (by my OCG) includes two regional versions of the Princeton Ocean Model. Also at USF, J. Walsh leads the biological modeling, K. Fanning provides nutrient data, and my co-investigator M. Luther assists with our Florida COMPS and our real-time Internet capabilites. Collected over the past year and now available for analysis are data from optical sensors deployed on my moorings by R. Maffione, HobiLabs.

## WORK COMPLETED

I initiated a WFS circulation study in 1993 in cooperation with the USGS. This expanded in 1995 with MMS and ONR support. The State of Florida then provided a Coastal Ocean Monitoring and Prediction System (COMPS) for real-time currents and surface fluxes offshore, and sea level and winds at the coast. USF, in partnership with others, was awarded an ECOHAB regional field study for the WFS by NOAA, and this evolution allowed the development of the present efforts.

Measurements began with a mid-shelf ADCP from 10/93 to 1/95. These data defined the relevant time scales of motion and showed a seasonal circulation cycle. Weisberg et al. (1996a, b) and Black (1998) present some of these findings. A trans-shelf ADCP array was then deployed between the 300m and the 30m isobaths over the period 1/95-2/96. Weisberg et al. (1997) and Siegel (1998) report on these data. They show an inner-shelf region where responses to synoptic weather forcing are well-defined, contrasted with an outer-shelf region where deep-ocean interactions are of increasing importance. Meyers et al. (2001) describe the outer-shelf features.

To examine the inner-shelf more closely, ADCPs were deployed off Sarasota, FL on the 20m and 25m isobaths in 11/96. They show the three-dimensional nature of the inner-shelf and the importance of baroclinicity even in shallow water. Seasonally, we observe a modulation of both the across-shelf and along-shelf transports.

Satellite imagery is playing an important role. Weisberg (1994) related SST patterns to Loop Current influence on the WFS. Weisberg, et al. (2000) report on a specific upwelling case study using satellite imagery, *in-situ* data, and a numerical model simulation. The case study winds were calm for several days prior to a wind-driven upwelling event, allowing us to view the response as an initial value problem. The Ekman/geostrophic route to spin-up is documented through a combination of *in-situ* analysis and numerical modeling, and most of our work combines the data analysis with the models.

Our numerical modeling is presently Princeton Ocean model (POM) based. We adopted a step-wise approach to modeling, first addressing relatively simple questions before advancing to more complete ones. For the seasonal cycle we first tested the hypothesis that monthly mean winds alone are capable of producing observed variability (Yang and Weisberg, 1999). The rejection of this hypothesis as incomplete led to the conclusion that baroclinicity via surface heat flux is an essential ingredient. Li and Weisberg (1999a,b) examined the WFS spin-up to switched on, spatially uniform winds. Through the model response kinematics and dynamics we began to develop an understanding for the three dimensional nature of the wind-forced WFS responses. This facilitated the actual baroclinic, wind forced upwelling event simulation previously cited. Such simulations advanced further with a month-long study of the WFS responses to the sequences of upwelling and downwelling observed in April 1998 (Weisberg et al., 2001). The model replicated the data well. We learned that stratification

greatly influences the responses and that the bottom Ekman layer response may be rectified such that upwelling favorable winds cause larger (in both offshore scale and magnitude) responses than downwelling favorable winds. This asymmetry, in both the model and the data, is explained on the basis of thermal wind effects, and it helps to define the inner-shelf. The scale of the inner-shelf is related to the sea surface slope set up by surface Ekman layer divergence. Because of the Taylor-Proudman theorem, a surface Ekman layer divergence requires a bottom Ekman layer convergence. Therefore, by controlling the bottom Ekman layer development, stratification leads to asymmetry in a way that can only be achieved in the fully three-dimensional flow field.

With these preliminary exercises completed, and with an expanded data set, we are now pursuing more complete model/*in-situ* data interactive studies. Our present model extends from the Mississippi River to the Florida Keys with resolution varying from 2 km near-shore to 6 km at the open boundary where a radiation condition is applied. Vertically, the model has 21 sigma layers, non-uniformly distributed to better resolve the surface and bottom Ekman layers. Hindcast studies are aimed at determining how much of the observed synoptic, seasonal, and inter-annual variability can be explained on the basis of local forcing. The first of these is a simulation of the circulation and temperature budget for the spring 1999 season transition (He and Weisberg, 2001a). On the basis of quantitative comparisons with data we use the model to describe the synoptic and seasonal variability. This paper confirms the hypothesis of Weisberg et al. (1996) that the southeastward mid-shelf in spring is the result of local, shelf-wide surface heat flux and wind forcing. It also explains the advection of low salinity water of Mississippi River origin that is found on the WFS each year and the physical basis for the formation of the so-called “Green River” observed in satellite imagery.

The 1999 hindcast was chosen as a first case because the shelf break hydrography showed minimal isoline slopes and hence minimal dynamical influence by the deep-ocean. Each of the three years sampled is different, however. For example, 1998 showed anomalously large isoline slopes at the shelf break and the anomalously high nutrients. Does this imply that the LC or its eddies controlled the WFS material property distributions that year, or, as in 1999, did local forcing hold sway? Figure 1 compares model simulated fields at the end of the spring season (May 31) in both years. 1998 (on the left) shows a stronger jet located farther offshore than 1999. It also shows a more developed low salinity tongue. All of these modeled features are a consequence of <u>local</u> forcing only; the LC is <u>not</u> included in the model. Weisberg and He (in preparation) consider the inter-annual variability on the WFS, and they conclude that the anomalous conditions of 1998 were primarily the result of <u>local</u> forcing. The synoptic scale wind variations were subtly different in that upwelling winds were stronger and longer lasting in 1998 than in 1999, which caused deeper, colder water with higher nutrient concentrations to be upwelled onto the shelf. This, combined with anomalous surface heat flux distributions, led to the observed differences. This is not to say that the adjacent deep-ocean is unimportant. Conditions there set the height of the material property isolines and hence the vertical distance over which they must upwell to breach the shelf. With the exception of large Rossby number events (for which the LC or an eddy may literally ride up on the slope), however, it is the local forcing that determines whether or not deep-ocean water properties can be advected onto the shelf. A companion paper, Walsh et al. (in preparation) provide the nutrient story and the combined effects of the physics and biology in determining the primary productivity. In effect, we have dispelled the myth that the LC is the primary agent controlling the WFS and we have replaced this with the (developing) understanding of how deep-ocean and local forcing combine to control WFS material properties.

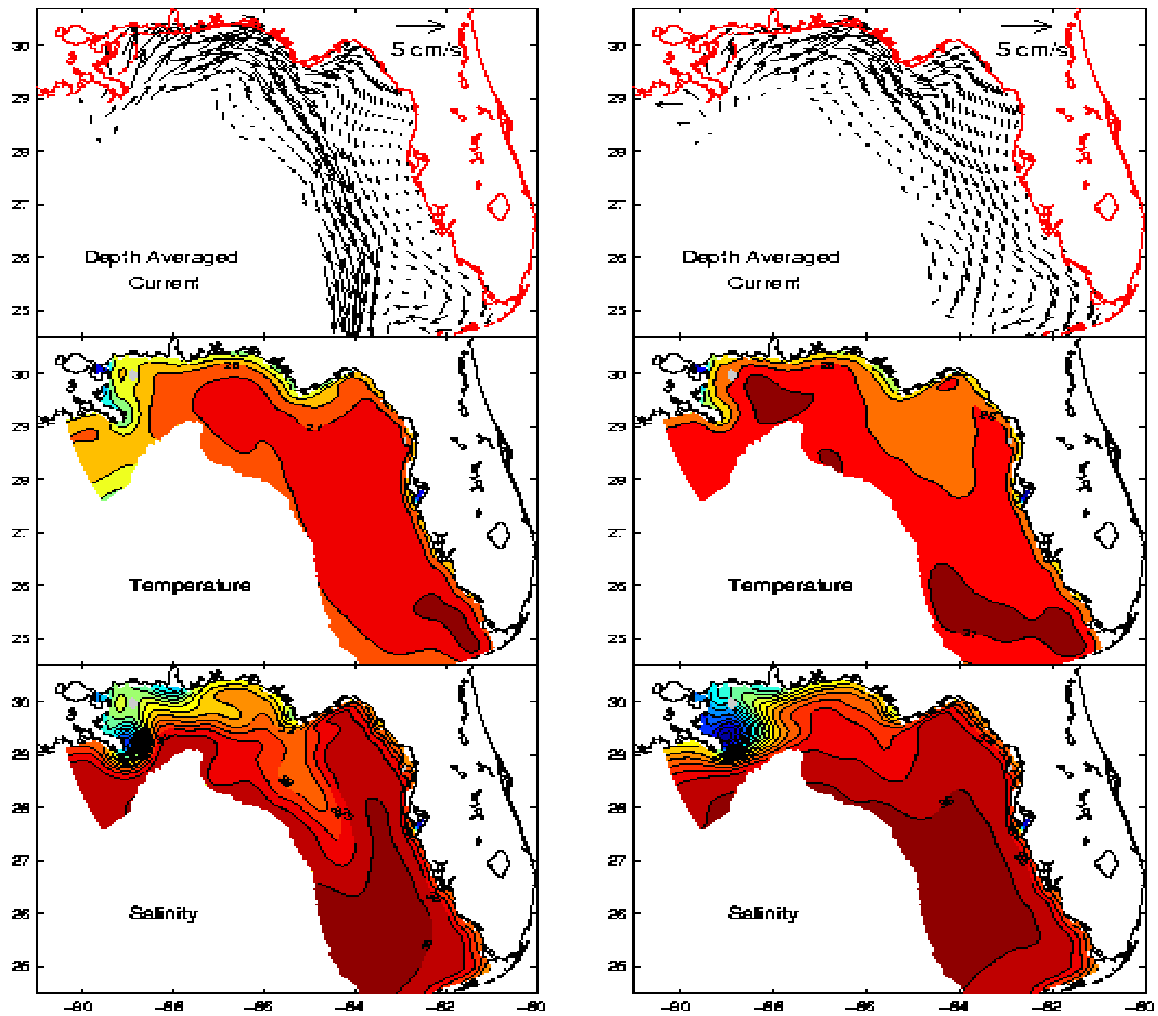


***Figure 1. Spring season fields on May 31 for 1998 (left) and 1999 (right) model simulations.***

Two additional accomplishments this year are noteworthy: i) the completion of a barotropic principal constituent tides study and ii) the implementation of a web-based nowcast/forecast model. He and Weisberg (2001b) provide a detailed comparison between modeled and observed sea level and velocity hodograph ellipses for the M2, S2. K1, and O1 constituents, and on the basis of this provide the co-amplitude, co-range, and hodograph maps for the model region. We also discuss Lagrangian trajectories due to tide-induced Stokes drift and the effect of the tides on bottom boundary layer induced mixing. The model results are complemented by our direct bottom boundary layer measurements. The nowcast/forecast model is forced by NOAA Eta model wind fields. Once the surface heat flux and rivers are added the model will be fully baroclinic. Presently, we update the nowcast and forecast each day at 0000UT and provide forecasts for the next 36 hours at 6 hour intervals. Shorter update intervals and archive capabilities are being developed. Maps of wind fields, sea level, and surface currents are available at http://OCG6.marine.usf.edu.

## RESULTS

FY01 results were achieved in all proposed areas. 1) We collected three years of currents, sea level, and hydrographic data, and we assisted R. Maffione (Hobilabs) with optics measurements on our moorings. 2) Real-time data elements are in place, and these are being made available to appropriate agencies and the public. These are now providing long time series of *in-situ* surface fluxes that are critical for shelf modeling. 4) We developed a regional circulation model (Mississippi River to Florida Keys) for hindcast/analysis studies and a regional nowcast/forecast model to support practical applications. Model/*in-situ* data comparisons were performed for circulation variations occurring on tidal, synoptic, seasonal, and inter-annual time scales. Coupled biological/physical modeling is also advancing. 5) We successfully performed our initial bottom boundary layer experiments and the data are presently being analyzed.

A significant new finding is that local forcing, independent of the Loop Current, largely controls the synoptic seasonal and inter-annual variability on the WFS.

## IMPACT/APPLICATIONS

Our physical oceanographic results are necessary inputs to biological/optical models. The 3-D, time dependent WFS circulation responses largely determines the chemical, geological, and biological properties to be sampled by sensors aboard AUVs, or flown on aircraft or satellites. Satellite sensors may offer only a limited view of inner-shelf workings. *In-situ* physical oceanographic data are necessary for interpreting ocean optical measurements made either *in-situ* or by remote techniques.

## TRANSITIONS

The physical/biological modeling efforts will transition to a WFS red-tide forecast model as part of the NOAA/EPA ECOHAB Program. Real time, Internet accessible measurements and models (e.g., hurricane storm surge) are also being used for emergency preparedness as part of the USF COMPS.

## RELATED PROJECTS

We are interacting with NOAA sponsored scientists to the south in Florida Bay (T. Lee) and with MMS sponsored scientists to the north in the Florida Big Bend (W. Sturges). The NOAA/EPA ECOHAB Program is co-located with our work (other P.I.s include J. Walsh, G. Vargo, K. Steidinger, G. Kirkpatrick). For HyCODE we are also interacting with K. Carder, R. Maffione, and others. We are playing leadership roles in evolving coastal ocean observing systems such as SURA-SCOOP.

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